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GEOHISTORICAL BACKGROUND OF THE POTENTIAL HYDROCARBON RESERVES IN HUNGARY

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INTRODUCTION

Year by year the importance of the hydrocarbons increases the world over, the countries increase their efforts to find more and more new deposits. In the appraisal of the perspectives of exploration both the geological and the economic conditions are equally decisive. The study of the amount of the prospective hydrocarbon reserves and of their probable distribution in space is a geological task, while the rentability analysis of the exploration is an economic problem.

The study of the geological conditions in the Carpathian Basin is motivated by the following considerations:

— The now-existing hydrocarbon deposits of Hungary were formed following the Alpine orogenesis. The accumulated desposits in the Early Palaeozoic period must have been mobilized and dispersed under the influence of the Variscan orogenesis, while those which were accumulated in Late Palaeozoic—Mesozoic time underwent in the same way the effect of the Alpine orogenesis.

— The Lower Palaeozoic mother rocks which were metamorphosed during Variscan orogenesis, lost their hydrocarbon contents, thus their potential reserve was not sufficient for the formation of hydrocarbon as early as Permian—Mesozoic time. Our attention has therefore been directed to the post-Variscan events.

— In Late Palaeozoic—Mesozoic time the area of the Carpathian Basin was part of the geosyncline of the Tethys, and in the Neogene it became the basin of the Pannonian inland sea. In the interest of an easier recognition of the relationships, we have therefore to consider the entire Pannonian Basin as well as the area of the Tethys surrounding it.

The purpose of the present concise review is to make known the fundamental directions with a view to such a long-term exploratory policy, according to which the exploratory operations have been made for 5 years with high economic efficiency. The paper is the first part of a long-range, collective multi-phase exploratory programme. Beside being an initiative, it is to determine the activities to be done in the future.

Even in this place we have to express our thanks to ELEMÉR SZÁDECZKY-KARDOSS, Academician, Secretary of the Earth Sciences and Mining Division and to JÓZSEF FÜLÖP, Corresponding Member of the Hungarian Academy of Sciences, who have for nearly 3 years inspired us and consulted with us in words and in writing, to GÁBOR PANTÓ, Corresponding Member, for his very precious remarks, to BARNA GÉCZY, D. Sci., for his complements showing new aspects, to KÁLMÁN BALOGH,

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FACIES BELTS AND PRE-ALPINE MORPHOLOGY OF THE TETHYS

On the basis of the data of the hydrocarbon exploration and development drillings made by the Hungarian Crude Oil and Natural Gas Trust, the basement of the Hungarian part of the Pannonian Basin is built *up of alternating belts* of Upper Palaeozoic—Mesozoic sedimentary rocks and crystalline — metamorphic formations [E. R. SCHMIDT, 1957]. In the area of our country four Upper Palaeozoic—Mesozoic belts and five crystalline—metamorphic trends separating and fringing them can be discerned [GY. WEIN, 1970]. In some of the mountains each belt is represented by outcrops. Corresponding to them, they are named the Bakony-, Bükk-, Mecsek- and Villány belts. T. SZALAI and GY. WEIN have given special names to the different crystalline—metamorphic belts.

The Upper-Palaeozoic—Mesozoic sequences of the Hungarian Central Mountains, and consequently, of the belts under consideration, *are different* [E. VADÁSZ, 1953] as manifested by both the vertical subdivisions and thicknesses of the sequences, and their lithological and palaeontological characteristics. Within certain belts the development is of the same type.

A great number of references have been published in Hungary on the *connections between* the Central Mountains and the Alpine-Carpathian-Dinaric areas. The geological connections of the Transdanubian Central Mountains with the Eastern Alps, the Gemerides and the Western Carpathians have been known since the beginning of this century. The Inner-Dinaric and South-Alpine characteristics of the Bükk-Mountains, formerly supposed to be Carpathian [F. HORUSITZKY, 1961, K. BALOGH, 1964], as well as the close relationship between the Mecsek and Villány Mts. [E. VADÁSZ, 1954; J. FÜLÖP, 1966; E. NAGY, 1969] are also proved facts. Although F. HORUSITZKY'S [1968] — and formerly KOBER'S [1931] — assumptions are not yet proved in detail, the present studies have led to similar results: *the E and the ENE facies belts, following the chain of the Carpathians turn first to the SE, then to the WSW.*

Of the facies belts, the *South Alpine—Bükk—Inner-Dinaric* belt shows such remarkable characteristics that it can always be readily separated from the surrounding belts. These characteristics are: marine Carboniferous and marine Permo-Triassic sediments of great thickness, Triassic and Jurassic ultrabasic—basic ophiolitic volcanism (Diabase—Chert Formation), the metamorphic nature of the Upper Palaeozoic—Mesozoic formations and the Inner-Dinaric and Inner-Carpathian flysch always associated with this belt. Because of this fact at first we deal with the areal extent of this belt.

The Upper Palaeozoic—Mesozoic Bükk development can be traced from the Karawanken through the Macelj Mts. to the Bükk Mts. by means of hydrocarbon exploratory wells drilled in the vicinity of Lepavina, Jagnjedovac, Inke, Iharosberény, Bajcsa, Pat, Budafa, Sávoly, Táska, Buzsák, Igal, Karád, Dinnyés, Bugyi and Tóalmás. In conformity with our assumption, such type of formations has also been reached by wells drilled near Šelnica, Medjimurje, Dravsko-Središte, Varašdin, Slanje, Ludbreg, Križevci, Toplovač and Légrád.

Its northern boundary is represented by the Balaton Crystalline Range trending from the Pohorje Mts. to the Velence Mts. (via Logarevci, Verzaj, Sl. Gorica, Sobota, Bakoći, Martijanci, Filovci, Pördeföldе, Eperjehegyhát, Pusztamagyaród, Gelse, Balatonhidvég, Ságvár), then by the Central Mountains Mesozoic as identified in boreholes at Tura near Gödöllő, S. JASKÓ [1946] assumed that the granites of the Velence Mts. was available underground here. Drilling wells at Recsk, Parádfürdő and Bükkszék have reached formations of Bükk facies, but in the NW part of the Recsk—Parádfürdő area, the mica-schist xenoliths within the andesite indicate already a crystalline basement [K. VARRÓK, 1959]. On account of the Ladinian sequence of Uppony and Szendrő, represented by cherts and quartzose and shaly rocks [M. MÉSZÁROS, 1961], the Rudabánya Mts. may belong to this zone, while the area of Perkupa and Jósvavölgy seems to belong to the Gemer facies. On the basis of their terrestrial Upper Carboniferous—Permian sequences the Zemplén Mts. are also associated to the former [M. MAHEL, 1968).

Its *Southern boundary* is indicated by the crystalline zone of Kaposfő—Mágocs [GY. WEIN, 1967] which can be traced with some interruptions from Zagreb to Kismarja (via Vrbovec, Cerje, Mosti, Szenta, Kutas, Jákó, Kaposfő, Cegléd, Túrkeve, Püspökladány, Furta, Körösszegapáti, Kismarja) [GY. WEIN, 1967] and by the Törtel—Nyírlugos flyschoid zone in its foreground patterned by Jurassic limestone reefs (Hajdúszoboszló, Ebes). In Rumania the bituminous and cherty Triassic limestones, the ophiolites connected with radiolarites and the flysch formations containig Jurassic reefs in the Turda—Lipova zone of the Transsylvanian Metalliferous Mountains [P. Rozlozsnik, 1937; L. NAGY, 1958; M. ILIE, 1961; CHEORGHIU, 1961] doubtlessly belong to the Bükk facies. The connection with them can be traced by following the occurrences of the Inner-Carpathian flysch — as believed by T. SZALAI as well — through the eruptive masses of the Oraşului—Gutăiului, the Sălaj, Baia-Mare and Oas subbasins, and then the Rodnei Alps up to the Transsylvanian Basin [L. NAGY, 1958]. The Turda—Lipova zone is separated by the Gilău-Zărand crystalline zone from the different Upper Palaeozoic—Mesozoic formations of the Apuseni Mts., while towards South it is bounded by the crystalline mass of the Rusca Alps. According to K. TELEGDI ROTH [1929], the Transsylvanian Metalliferous Mts., "*following the bend* of the arch of the Balkan-Mts., fit in the continuations of the North-Serbian tuffite formations, interrupted with the Pannonian subsidence". This connection does exist there without doubt, as affirmed by drilling in Jugoslavia, at Meda, Begejci, Melnici, Bečej, Gospodinci, Temerin, Stepanovo, Silbas, Plavna, Vulkovar, Konak, Boka, Zitiste, Lazarevo, Zrenjanin, Elemir, Orlovat, Samos, Padina, Alibunar, Gloganj, Ovca, Omolica, Semberija, Korace, where flysch formations containing Jurassic Limestone reefs and serpentines have been found and by the ophiolite of the Fruska—Gora traceable as grading into the serpentine—flysch zone of Bosnia. In Jugoslavia, on the northern margin of the flysch zone the holes drilled near Mokrin, Boka, Kikinda, Crnja, Idos, Milosevo, Ada, Feketič, Rada, Turja, Sirig, Srborban, Kula, Darda, Osijek, Bizovac, Klokocevci, Nasice, Djakovo, Bosna Gradiska, Visoko Greda, and Bunjani, — and the intrusive and metamorphic formations of the Papuk Mts. represent the continuations of the Kaposfő—Mágocs—Gyalu—Zaránd crystalline zone.

On the basis of the foregoings the *Upper Palaeozoic—Mesozoic zone,* characterized by *Bükk facies types* and covered by Cretaceous—Paleogene flysch in most of the area *can be traced from the Karawanken through the Bükk Mts. and the Transsylvanian Metalliferous Mts. to the Inner-Dinarides.* It is also without doubt according to the studies of. D. NIKOLIČ—R. KEMENCI [1970].

The Upper Palaeozoic—Mesozoic belt of the *Mecsek Mts. range* stretches from the vicinity of Sedlarča Ferdinandovac—Vizvár (through the boreholes drilled in the neighbourhood of Kurd, Tolnanémedi, Kiskőrös, Izsák, and Kerekegyháza in the Danube—Tisza Interfluve) to Nagykőrös—Szank. In the north it is bounded by the hypothetical Kaposfő—Cegléd zone, while in the south by the Mórágy—Pálmonostora (Babócsa, Pécs, Mórágy, Miske, Szank, Pálmonostora, Pusztaföldvár), crystalline zone. In the Trans-Tisza Region (E of the Tisza river), the Tertiary formations between Szentes and Gyula have not been yet penetrated by drillings so that their extension towards teh Apuseni Mts. can be only supposed. According to our hypothesis, the boreholes drilled near N. Kulzovac, Nadoljan, Velebit, Szenta, Gornibreg, Bajsa, Benicanci, Gojlo, and the Upper Palaeozoic—Mesozoic formations of Papuk Mts. mark the extension of this belt beyond the Codru Mts.

South of the crystalline zone of Mórágy, the Upper Palaeozoic—Mesozoic section of the *Villány Mts.* extends through the drilled holes of Komlósd, Kálmáncsa, Szulok, Szigetvár, Bogádmindszent and Téseny to the Villány Mts., in the southern part of the Danube-Tisza Interfluve (Érsekcsanád, Rém, Jánoshalma) to Eresztő, Pusztamérges and Ásotthalom, and farther away presumably well into the Trans-Tisza Region, up to Tótkomlós—Pusztaszöllős. This belt is separated from the Bihor zone by the Battonya—Szeged—Palics crystalline zone, regarded as the continuation of the Mórágy crystalline belt.

The Transdanubian Central Mountains, to the north of the Lake Balaton crystalline zone extend northwards into the so-called Drava zone and into the Gailtal Alps [E. VADÁSZ, 1954], while in NE direction they can be traced in the South-Gemer part [F. HORUSITZKY, 1961] of the southern zone of the Western Inner-Carpathian [M. MAHEL, 1968]. To the north of this Upper Palaeozoic—Mesozoic belt, the *middle crystalline belt* of the Eastern Alps can be traced from Kőszeg, through Mihályi and Kolarovo, to the Spiš—Gemer Metalliferous Mts. North of the middle crystalline belt there is the Upper Palaeozoic—Mesozoic belt of the *Northern Calcareous Alps,* having a completely similar development to that of the belt of the Central Mountains, which as shown by recent studies, have their continuation in the Northern Gemer and "Choč" sequences [M. MAHEL, 1961] of the northern Inner-Carpathians [M. MAHEL, 1968] East of the Zemplén Mts. these two mesozoic belts plunge underground and are re-exposed first in the *East-Alpine or Austro-Alpine* [M. MAHEL, 1968] uniformly crystalline Mesozoic belt of the Eastern-, and then of the Southern Carpathians [L. NAGY, 1958]. The outermost Mesozoic zone of the area being considered represented by the Križna, Manin and "Mantle" sequences [M. MAHEL, 1961] showing a so-called Carpathian [K. TELEGDI ROTH, 1929] or a *Central-Carpathian* [M. MAHEL, 1958] development and belonging to the central and northern (Klippen Belt) zone in the Western Inner-Carpathians. This Mesozoic development, including the Paleogene flysch, is bounded by the Outer or Flysch Carpathians extending equally in E, W and N directions. And it may be assumed that the Carpathian facies extends to the E and W into the flysch basement.

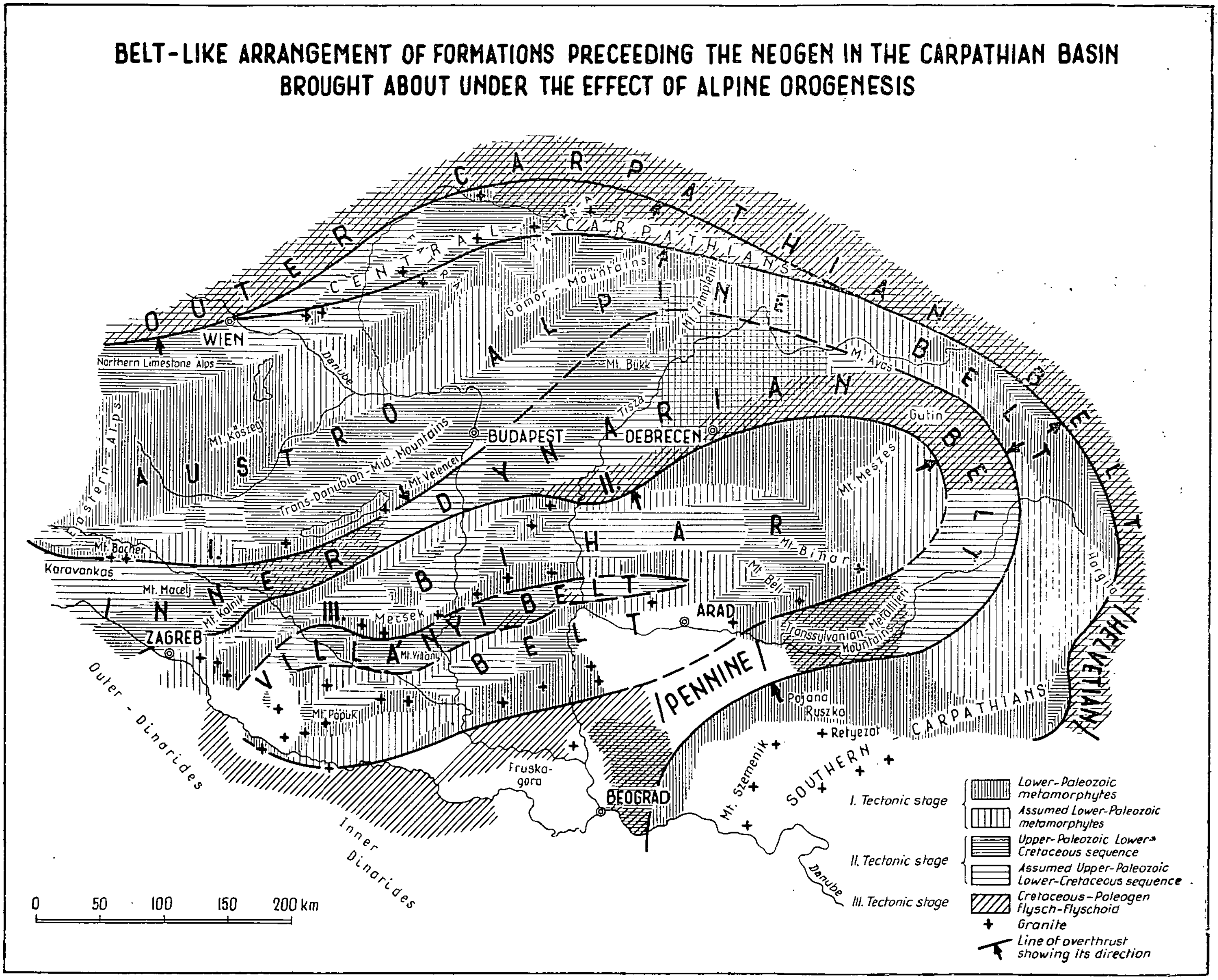
BELT-LIKE ARRANGEMENT OF FORMATIONS PRECEEDING THE NEOGEN IN THE CARPATHIAN BASIN
BROUGHT ABOUT UNDER THE EFFECT OF ALPINE OROGENESIS
OUTER CARPATHIAN BELT
CENTRAL CARPATHIANS
TATRA
Gömör - Mountains
ALPIN
AUSTRO ALPIN
DYNARIAN BELT
INNER DYNARIAN BELT
HARBI
HARBIHAR BELT
VILLANYI BELT
PENNINE
HELVETIAN
WIEN
BUDAPEST
DEBRECEN
ZAGREB
ARAD
BEOGRAD
Northern Limestone Alps
Eastern Alps
Danube
Mt. Kőszeg
Trans-Danubian - Mid - Mountains
Mt. Velencei
Mt. Bükk
Mt. Zemplein
Tisza
Mt. Avas
Gutin
Mt. Meszes
Mt. Bihar
Mt. Beli
Mt. Bacher
Karavankas
Mt. Macelj
Mt. Kalnik
Mecsek
Mt. Villany
Mt. Papuk
Fruska-gora
Transsylvanian - Metalliferi Mountains
Pojana Ruszka
Retyezat
Mt. Szemenik
SOUTHERN CARPATHIANS
Outer - Dinarides
Inner Dinarides
I.
II.
III.
0 50 100 150 200 km
I. Tectonic stage
II. Tectonic stage
III. Tectonic stage
Lower-Paleozoic metamorphytes
Assumed Lower-Paleozoic metamorphytes
Upper-Paleozoic Lower-Cretaceous sequence
Assumed Upper-Paleozoic Lower-Cretaceous sequence
Cretaceous-Paleogen flysch-flyschoid
Granite
Line of overthrust showing its direction

Fig. 1.

In *summary* it can be stated that *five facies belts of the Upper-Palaeozoic—Mesozoic formations in the Carpathian Basin* are known: the *Central- and Outer Carpathian* belt; the East-Alpine—South-Alpine or *Austro-Alpine* belt, which in the Zemplén Mountains is divided into two branches (Northern Calcareous Alps — Northern Gemerides, Gailtal Alps — Southern Gemeriden); the *Karawanken—Bükk—Transsylvanian Metalliferous Mts.—Inner-Dinarides* belt; the *Mecsek—Bihor—Papuk* belt, and the *Villány* belt.

In Upper Palaeozoic time the *Central- and Outer-Carpathian*—hereafter referred to briefly as *Outer-Carpathian*—belt still was a part of the North-European continent. The Lower—Triassic is characterized by the great quantity of quartzite, the Middle Triassic by limestones and dolomites poor in fossiles, the Carnien—Norian by the Keuper facies, the Rhaetian by the a pelitic—lumachelle facies. These characteristics are similar to the epicontinental, so-called "Germanic", Triassic. Therefore this belt is developed in the northern part of the Western Alps. While on the northern fringe of the Eastern Alps it can be considered a constituent of the flysch belt basement and a *continuation of the Helvetian facies* showing similar characteristics, *while the Central-Carpathian belt can be considered a tectonic window of the Helvetian facies.* The lower and middle parts of the Jurassic, having a small thickness, consist of shallow-water, cherty sandstones, shales and crinoidal limestones. A typical facies of the lower part of the Malm is the red radiolarite, while that of the Titonian is the shallow-water, cherty limestone with a pelite content increasing upwards. The Lower Cretaceous is of flysch facies.

The *Austro-Alpine facies belt* is characterized by a terrestrial Upper Palaeozoic (in the neighbourhood of Dobšina and in the Zemplén-Mts. littoral detrital—lagoonal Upper Carboniferous); by Permian quartzous porphyry, by a littoral, detrital—lagoonal Lower Triassic grading into a neritic, offshore calcareous—dolomitic Middle and Upper Triassic of great thickness with insignificant "pietra verde" traces of volcanism in the Middle-Triassic, and with a Kössen and Lunz facies in the uppermost Triassic; by a deep-water Jurassic of low thickness, lacking terrigenous materials, discontinuous and incomplete ammonitic, including sublittoral (Gresten) facies in the Lias, and shallow-water (Hierlatz) facies in the Lias and Dogger, and by a bathyal and shallow-water Lower Cretaceous.

The Upper-Paleozoic of the *Karawanken—Bükk—Inner-Dinaric* (referred to hereafter briefly just as Inner-Dinaric) belt is a thick neritic sequence of sediments interrupted by terrestrial levels. In the Alps the Lower and Upper Carboniferous separated by a hiatus, as well as the Lower Permian are near-shore detrital—calcareous sediments of grauwacke type, the Middle Permian is terrestrial (Gröden sandstone), and the Upper-Permian is a neritic Bellerophon limestone and dolomite interbedded with sandstone and gypsum. Although there are no references to the presence of Jurassic formations in the Bükk-Mts. the Triassic and Jurassic are characterized there by a pelagic sedimentation, calcareous and pelitic, and by basic and ultrabasic rocks (ophiolites) mixed with cherty schist with Radiolaria (diabase—chert formation, K. Petkovic, 1961). In this sense the basic volcanites of Szarvaskő, Tóalmás and Inke could have formed in the Triassic or Jurassic periods. The Lower Cretaceous is of a flysch facies. Metamorphism of various degree is significant, being characteristic of the whole Carboniferous—Jurassic sequence. These peculiarities, compared to the characteristics of the Pennine facies of the Western Alps (very thick Carboniferous, with deep-sea Triassic—Jurassic radiolarites and ophiolites, anchi-metamorphic character), make it plausible to assume that the *Inner-Dinaric*

Upper Palaeozoic—Mesozoic belt is a continuation of the Pennine facies belt of the Western Alps.

The Mecsek—Bihar belt is characterized by a thick, terrestrial Upper Carboniferous—Permian, with Permian quartzporphyry, by a transgressive (lagoonal-detrital) Lower-Triassic, a shallow-water calcareous—dolomitic Middle Triassic and Upper-Triassic becoming gradually continental from the Karnian on. The Lias having a great thickness is of the Gresten facies (Mecsek, Kiskőrös, Szank, Bihor), then towards the Jurassic it becomes pelagic, in the Malm with a net chemical sedimentation. The Lower Cretaceous is entirely represented by a regressive sequence with a break in sedimentation, and with a vigorous basic subaquatic volcanism in the Mecsek.

The poorly known *Villány belt* is characterized by a continental Upper Carboniferous and Permian, by an incomplete Triassic and Jurassic, by the Lias of Adneth facies (Eresztő, Pusztamérges, Pusztaszőllős, Tótkomlós), by a shallow-water Dogger and Malm limestones, by a Neocomian hiatus with traces of a trachydolerite volcanism and by limestones of Urgonian facies [J. FÜLÖP, 1966].

Beyond Zagreb the Bihor—Villány belt collides with the Outer-Dinarides of opposite strike. Their relation with the Outer-Dinarides is to be studied in the future. *We think it possible that the belt of the Bihor and Villány is a continuation of the Outer-Dinaric belt in the Carpathian Basin.*

According to E. VADÁSZ [1954], T. SZALAI [1958, 1959], GY. WEIN [1966, 1970] and F. HORUSITZKY [1968], the Hungarian Central Mountains and the series of strata in the belts previously distinguished are not the heteropic facies of one and the same uniform geosyncline, but they are sediments of subgeosynclines separated by isthmuses, rows of isles and seamounts. K. BALOGH [1964] does not think it necessary to justify the existing facies alterations by supposing a separating ridge; that is, in his opinion the Bükk and Gemer sediments would have settled in different parts of one and the same uniform sedimentary basin. In 1960 E. VADÁSZ has also taken a stand on that. ("There is no obstacle in the way of believing that the Triassic members of the Hungarian Central Mountains could be considered a Triassic sea starting from the Alps through the Bükk-Mts., together with the area of the Slovakian Karst with a continuous, — but dissected bottom or — possibly a geosyncline-.")*According to the idea of* KOBER, STAUB *and others, the Mesozoic geosyncline of the Tethys was a sea-basin similar to the present world oceans, with well distinguished and diversified facies and true oceanic depths* [in K. TELEGDI ROTH, 1929]. Taking into account that the Nort—German—Polish (Germanic) Triassic is continental—epipelagic, the Outer-Carpathian (Helvetian) facies is of a transitional type, the Austro-Alpine is shallow-marine — with an increasing pelite content towards the Helvetian belt [M. MAHEL, 1961] — the Inner-Dinaric (Pennine) facies is of abyssal development and of a thickness corresponding to this; furthermore that the formations of the Austro—Alpine and of the Inner-Dinaric belts from the Middle Triassic to the Lower Cretaceous do not contain any littoral detrital sediment, which would suggest the proximity of a continent ("coastless" belts as referred to by E. VADÁSZ, 1954, E. R. SCHMIDT, 1957), *the conception of* KOBER, STAUB, K. BALOGH and E. VADÁSZ [1960] *seems to be justified.* The axis of the geosyncline was formed by the Pennine belt, and its northern edge by the Germanic area. The Bihor—Villány and Outer-Dinaric belts could have belonged already to the southern half of the geosyncline. According to the statement of E. VADÁSZ [1960], "the differences in the development of our mountains are ultimately due to a specific crust structure, as well as they are influencing factors of the later crustal movements".

The *pre-Alpine morphology* of the studied part of the Tethys can briefly be summarized as follows:

The innermost belt of the geosyncline (Inner-Dinaric belt) was covered by a shallow sea already in the *Late Palaeozoic periods* ("The geosyncline state is oldest here", F. HORUSITZKY, 1961). The surrounding parts of the area are at the same time emergent land surfaces with continental—littoral sediment form the Upper Carboniferous and with a final volcanism in the Lower Permian.

In the *Triassic*, with the progress of transgression, the sea of the Inner-Dinaric belt reached an abyssal depth and was the scenery of the initial ophiolitic volcanism of the Alpine orogenesis, which "is characteristic of the early subsidence-and-sedimentation stage in the evolution of the orogenic belts... of the marginal, partly abyssal graben-trough zone of the oceans" [E. SZÁDECZKY KARDOSS, 1968]. The neritic sedimentation at the same time shifted unto the area of the surrounding belts. In the Austro-Alpine belt a detrital—lagoonal littoral, then from the Middle Triassic a neritic carbonate sedimentation took place. Taking the statement of G. PANTÓ [1961] into account, the thin volcanic tuff layers, the so-called "pietra verde" of the Ladinian stage ("Its halmyrolytically decomposed material was transported by sea currents from remote submarine volcanic activities") may be derived from the submarine volcanoes of the Inner-Dinaric belt. The edge of the basin in the north is represented by the North-European continent, on the margin of which an epicontinental, tripartite, so-called "Germanic" Triassic has evolved. The Triassic of the Outer-Carpathian belt is a transition between the Germanic and Austro-Alpine developments. South of the Inner-Dinaric belt, in various parts of the Mecsek—Villány belt both neritic and transitional features can be found.

In the *Upper Triassic* a general regression is recognizable over the whole studied area of the Tethys. This becomes apparent in the area of the Germanic and Outer-Carpathian belt, so that the sedimentation becomes continental sublittoral (Keuper), in the Villány belt it is clearly manifested by the lack of sediments, being recognizable (Kössen and Lunz facies) even in the neritic regions (Austro-Alpine and Bihor belts).

At the end of the Triassic, at the onset of the *Jurassic period* a new transgression of the sea began which was characterized by the Gresten facies accompanied by coal formation in many places on the edges of the emerged land areas. The increasing transgression was marked by the fact that the Austro-Alpine belt became pelagic, the German and Villány areas neritic, and by the superposition of the Dogger—Malm deposits upon an older basement in several places. Simultaneously, the axis of the West-Carpathian sedimentary basin migrated to the north [M. MAHEL, 1961, 1968]. The extent of the Tethys reached its culmination at the beginning of the Malm. In the Tithonian already some symptoms of regression can be recognized, and in *Early Cretaceous* time chemical sedimentation was accompanied by the introduction of terrigenous material even in the innermost belts.

STRUCTURAL CONDITIONS OF THE PRE-NEOGENE FORMATIONS, AND CRETACEOUS-PALEOGENE MORPHOLOGY

In the area of our country "the orogenesis seems to have resulted in piling up and compression of formations that used to be distributed over larger areas" [K. TELEGDI ROTH, 1929]. In the Bakony "the marine facies of a great part of the Mesozoic sediments can only be imagined by supposing an intense piling up, because of the proximity of the Velence-Balaton crystalline belt which was terrestrial at that time..." [E. VADÁSZ, 1954]. This "...is generally recognizable in the structure of the mountains in different measure" [E. VADÁSZ, 1960]. The presence of such a compression-imbrication structure — with overthrusts similar to the classic "Litér fault" [F. PÁVAI VAJNA, 1930], — is clearly evidenced by the recent results obtained, also on the basis of deep drilling, for the Central-Mountains — e. g. the Apuseni Mountains in Transsylvania.

Similarly to the Hungarian Central Mountains, a system of compressional-longitudinal and disjunctive—transversal fractures is typical also of the belts distinguished in the present paper [E. R. SCHMIDT, 1957]. The direction of the longitudinal fractures,

SCHEMATIC STRUCTURAL SECTION OF THE OVERTHRUSTED GREAT STRUCTURAL UNITS

(Prepared by using the figure of E.R.Schmidt)

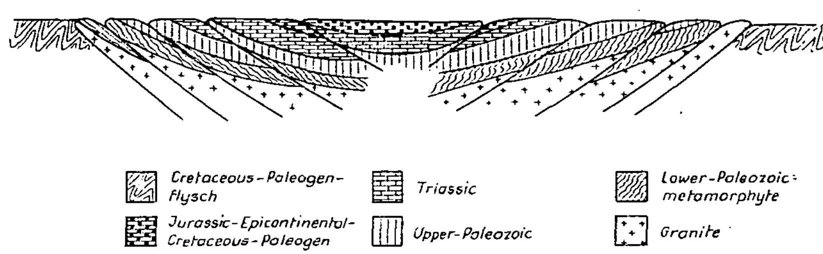

Fig. 2.

following the strike of the belts, is SW-NE and WSE-ENE, respectively, but in the Padurea Craiului-Bihor-Gilău-Codrului zone, parallel to the strike of the Eastern Carpathians, it is N-S [P. ROZLOZSNIK, 1937, M. ILIE, 1961]. In the Moma and Transsylvanian Metalliferous Mountains, just like in the Southern Carpathians, these fractures trend ENE-WSE [P. ROZLOZSNIK, 1937, M. ILIE, 1961], in the Inner-Dinarides NNW-SSE [STEVANOVIČ, 1964].

In respect of the details of the imbricated structure, *the Central Mountains and the belts under consideration are "asymmetrically two-flanked mountain structures, with an outward...* tending *movement,* and with more vigorously dislocated mountain-flanks on the side exposed to the more efficient power. The *two flanks are generally separated by a trough* having the character of a syncline" [E. R. SCHMIDT, 1954]. "It is always the southern to southeastern flanks that are more vigorously affected by tectonic deformation" [E. R. SCHMIDT, 1961]. This structural arrangement could be

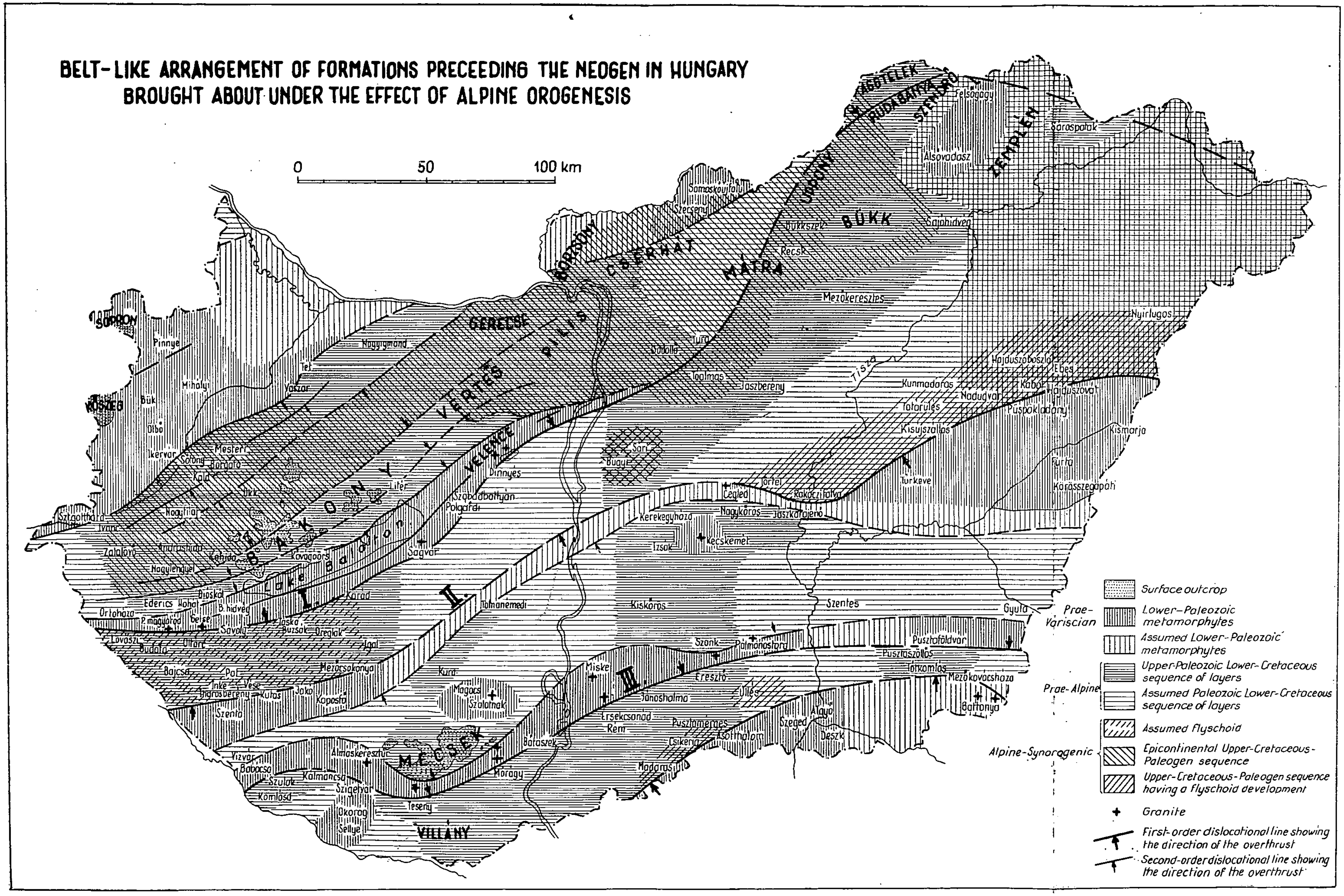
BELT-LIKE ARRANGEMENT OF FORMATIONS PRECEEDING THE NEOGEN IN HUNGARY BROUGHT ABOUT UNDER THE EFFECT OF ALPINE OROGENESIS
0
50
100 km
Prae-Variscian
Prae-Alpine
Alpine-Synorogenic
Surface outcrop
Lower-Paleozoic metamorphytes
Assumed Lower-Paleozoic metamorphytes
Upper-Paleozoic Lower-Cretaceous sequence of layers
Assumed Paleozoic Lower-Cretaceous sequence of layers
Assumed flyschoid
Epicontinental Upper-Cretaceous-Paleogen sequence
Upper-Cretaceous-Paleogen sequence having a flyschoid development
Granite
First-order dislocational line showing the direction of the overthrust
Second-order dislocational line showing the direction of the overthrust
AGGTELEK
RUDABÁNYA
SZENDRŐ
ZEMPLÉN
UPPONY
BÜKK
MÁTRA
CSERHÁT
BÖRZSÖNY
GERECSE
PILIS
VÉRTES
VELENCE
BAKONY
Lake Balaton
MECSEK
VILLÁNY
I.
II.
III.
Tisza
Sopron
Kőszeg
Szeged
Kecskemét
Gyula

Fig. 3.

doubtlessly demonstrated in the Mecsek [E. R. SCHMIDT, 1957, G. HÁMOR, 1964], the Bükk [E. R. SCHMIDT, 1967, K. BALOGH, 1964], the northern and southern Gemerides [M. MAHEL, 1961], and most recently in the Villány Mountains [GY. WEIN, 1967]. The Transdanubian Central Mountains are, according to the concept of L. KŐRÖSSY [1963], a regional monocline with a NW dip. The prevailing dip direction in the Bakony is NW, but already H. TEGER and K. TELEGDI ROTH showed the presence of a SE dipping counter-flank in the NW Bakony Mts. (Pápa) [E. VADÁSZ, 1953]. In the course of our present studies, in the continuations under the Bakony basin-sediments we came — coinciding with the studies made by F. HORUSITZKY [1961] in the Buda-Mountains and by GY. NAGY [1964] in the Gerecse Mountains — to the recognition that the Upper Permian-Lower Carnian beds crop out from the Upper-Carnian, Norian Hauptdolomit only on the NW and SE edge of the mountains along the Balaton and Kőszeg-Mihályi crystalline zones (Borgáta, Mesteri, Tét, Káld, Dióskál, Ortaháza, Kővágóörs) on the erosional surface of the Triassic sequence, while the Hauptdolomite is covered by Rhaetian formations — with Jurassic and remainders — in the central part of the area, around its longitudinal axis (from Nagylengyel to the Gerecse). This setting applying to the entire megatectonical unit, testifies to the occurrence of a trough-like structural from having a NE—SW axis, which was named synclinorium by K. TELEGDI ROTH, syneclisis by E. VADÁSZ, and tectonic trough (geoalveous) by E. R. SCHMIDT.

From the trough-like structure of our Upper Palaeozoic—Mesozoic belts, divided into bilaterally symmetrical thrust-sheet ranges, and from the relatively small difference in altitude it is clear that progressing from the axial lines of the belts towards their edges, older and older formations follow each other, in general. *The magmatic—metamorphic zones bordering the Permian—Lower Triassic thrust-sheets are the outermost thrust-sheet ranges of the belts under consideration, in which the deepest structural stages of the Hungarian mountains are exposed.* This is also evidenced by the size of the crystalline zone alongside the Balaton (250 km long, and 5—10 km wide), moreover, by the strong tectonical influences affecting the granite [A. KŐHÁTI, 1964], further by tectonized breccia zones observable in many places (Szilágyi-1, Pécs-7) between the granite—metamorphites and the Permian—Mesozoic formations in the Mecsek-Mts. [G. HÁMOR, 1964]. *The two-phase* intrusion of the granite (basic granite—microgranite) *is just an illusion due to the present tectonical setting,* since three horizons (Lower Palaeozoic metamorphites, Lower Palaeozoic metamorphites pierced by granite dykes, and granite) of a deeper structural stage have come into a juxtaposition along reverse fault lines. In our opinion, such a mechanism may account for the tectonic contact between the so-called basic granite and the Silurian—Devonian schist sequence, lacking any contact-metamorphism, melting-in or injections an accompanied in some places (Meleg--Mountain—Antónia-Mountain) by the formation a brecciated zone reaching even 100 m in thickness [E. VADÁSZ, 1960].

Each Upper Palaeozoic—Mesozoic belt and the corresponding magmatic—metamorphic zones are, therefore, different structural stages of the same megatectonic unit. The megatectonic units are separated from one another by dislocation lines of the first order, „belts having an orogenic character", along which the edges of the structural units have been piled upon one another [L. KŐRÖSSY, 1963].

I. The *„Balaton line"* [T. SZALAY, 1958], which is named by E. VADÁSZ [1954], together with the second-order dislocation lines, „the belt of the South Alpine piling", is the overthrust zone separating the Inner-Dinaric and Austro-Alpine megatectonic units on the southern boundary of the Balaton crystalline zone [L. DUBAY, 1962, L. KŐRÖSSY, 1963] and may be considered a continuation of the fault in Gailtal, Austria. In our country it is accompanied by the Upper Eocene andesite volcanoes (Hahót—Ederics, Velence Mts., Recsk), but a significant Tertiary volcanism is associated with it in Serbia, as well. Along this dislocation belt the *Inner-Dinaric unit thrusted under the Austro-Alpine* one. In the territory of our country it is proved by the following: in the South Zala area a detrital—pelitic sequence, locally about 2000 m thick, overlying a Mesozoic of Bükk facies, affected by strong tectonic deformation and dated, on the strength of deep drilling at Budafa, as corresponding to the interval between the Upper Cretaceous and the Helvetian (flyschoid?), has its northern boundary exactly coinciding with the Balaton line („The coincidence of the boundaries of the sediment-extension with the great tectonic lines is only evident in case of orogenic overthrusts", GY. KERTAI, 1961). The boreholes drilled at Buzsák [L. DUBAY, 1962] and Drávaszerdahely [V. DANK, 1962] have reached the Oligocene under Palaeozoic and Triassic formations, respectively. As observable in the lead-ore-exploring drifts of Szabadbattyán, in the course of the tectonic brecciation East-Alpine Devonian limestones must have thrusted over Lower Carboniferous deposits of Bükk facies [A. FÖLDVÁRI, 1952]. The most important evidence of the location of the Inner-Dinaric (Pennine) belt under the Austro-Alpine zone is the High Tauern and its cropping out in the Lower Engadin window [TERMIER, 1903]. Whith a view to the sequence of anchimetamorphic clay-marl shales and sandstones—conglomerates of borehole Ikervár-2, containing — as determined by J. KŐVÁRY — Upper Jurassic—Lower Cretaceous fossils, it is possible that a part of the metamorphites of the Little Hungarian Plain, adjacent to the Kőszeg—Rohonc Mts. [E. R. SCHMIDT, 1956; A. TOLLMANN, 1959; A. FAHR, 1960] is also an erosional exposure of the Pennine—Inner-Dinaric formations. Joining in STAUB's and KOBER's opinion, the Austro-Alpine, Gaetic nappe (Group *I*) of the Southern Carpathians, underlain by the so-called Danubian Autochtone (Group *II*) can also be regarded as an exposure of the Inner-Dinaric unit. This fact is — in our opinion — proved by the metamorphic character of the Upper Palaeozoic—Mesozoic formations lying on the crystalline schists of Group *II*, by the flysch facies of its Lower Cretaceous member and by the ophiolites occurring along the overthrust plane.

The *IInd tectonic line* or the „Szolnok—Ebes dislocation belt" [L. KŐRÖSSY, 1963], or the „Zagreb—Kulcs fracture" [GY. WEIN, 1970] is a first-order dislocation zone separating the Inner-Dinaric unit and the Kaposfő—Cegléd crystalline zone forming the northern edge of the Bihor Mts. Information about its character is available in southwestern Transdanubia, in the northern Trans-Tisza Region, and in the Apuseni Mts. of Transsylvania. In southwestern Transdanubia this line can be traced from the neighbourhood of Inke—Vése—Szenta up to Mezőcsokonya, on its northern side the hydrocarbon-exploratory wells have discovered, above the Palaeozoic—Mesozoic beds, a detrital—pelitic sequence of great thickness, covered for the most part by the Upper—Helvetian andesite and rhyolite volcanics already mentioned and taken earlier to be a fresh-water formation. On its southern side (Szenta, Kutas, Jákó, Kaposfő) the detrital sequence is absent and the igneous formations rest directly on the Lower Palaeozoic metamorphites. In the northern Trans-Tisza Region, from Szolnok to Debrecen, this dislocation line can be uniformly well traced. To the north of that, under the Neogene, the boreholes have reached Cretaceous—Paleogene flyschoid formations containing Jurassic limestone reefs (and underlain by diabase and Palaeozoic rocks); to the south Lower Palaeozoic metamorphites have been cut by drilling. This latter zone was also interpreted as an overthrust line first by GY. KERTAI [1961], then by L. KŐRÖSSY [1963], too. On the basins of GY. KERTAI's cited statement it has been proved also for southwestern Transdanubia, that the „Trans-Tisza crystalline schist zone" (GY. WEIN), forming the northern thrust-sheet ranges of the *Bihor megatectonic unit, has thrusted upon the Inner-Dinaric unit covered by flyschoid formations.* The same is proved by the thrusting of the formations fo the Transsylvanian Apuseni Mts. over the flysch sequence of the Transsylvanian Metalliferous Mountains [M. ILIE, 1961].

The *IIIrd tectonical line* is the contact between the Villány belt and the northern and southern arches of the Bihor belt, along which — according to our hypothesis — the Villány belt has thrusted under the Mecsek belt.

Towards the exterior, the Austro-Alpine belt has thrusted, also along a significant dislocation line, over the Outer—Carpathian unit covered by Cretaceous—Palaeogene flysch, as demonstrated by many authors. The „Choc" dolomite of Austro-Alpine facies could therefore have got into an Outer-Carpathian facies environment.

The structure of the *Austro-Alpine belt,* in the immediate vicinity of our country up to the Zemplén Mts. *can be classified as a double trough structure* consisting of longitudinal thrust-sheet ranges and overthrust blocks, the southern trough being represented by the Transdanubian Central Mountains and the Southern Gemerides the northern one by the zone of the northern Calcareous Alps and Northern Gemerides. The Little Hungarian Plain—Slovakian Metalliferous Mountains *metamorphic belt separating the two troughs, is a lower structural stage exposed to the erosional surface in the domed portion, which in some places* (Ikervár) *seems to have been eroded down to the Pennine unit forming the basement.* According to the present studies and to the results of the most recent refraction measurements [I. VARGA, K. VÁNDOR, GY. SÁGHI, 1967], the Rába line [V. SCHEFFER, 1948] is an outcrop of strata along a second- or third-order dislocation line rather than being a first-order dislocation belt [L. KŐRÖSSY, 1965].

Summarizing the above considerations, let us conclude that *in the Alpine-Carpathian system three down-thrusted megatectonic units* (Villány, Inner-Dinarian and Outer-Carpathian) *and two overthrusted ones* (Austro-Alpine and Bihor) can be distinguished. In the Alps and the Carpathians the Pennine windows (Tauern, Engadin, Danubian) emerging from under the Austro-Alpine belt and the Austro-Alpine „Choc" dolomite inserted into an Outer-Carpathian facies realm, are evidence of significant nappe overthrust movements. *Within the garland of the Carpathians, the sizes of overlapping due to block-piling claim further investigations.* Considerations of crust structure [F. HORUSITZKY, 1961; E. SZÁDECZKY KARDOSS, 1970] and the structural conditions of the central mountains under study indicate that these movements *in the territory of our country cannot have reached the order of magnitude of nappe* translation movements.

Having a bilaterally symmetrical imbricated structure and characterized by block-piling, the megatectonic units of Hungary have obviously been formed simultaneously, under the same power effect.

In the territory of the under-thrusted units in the vicinity of the first-order (I, II, III) lines of dislocation the Cretaceous—Paleogene formations exhibit for the most part a flysch — flyschoid facies, being epicontinental in the overthrusted units. Since the formation of the flysch lasted from the Early Cretaceous (in some places already from the and of the Jurassic) till Latest Palaeogene time, and since, according to K. TELEGDI ROTH's [1929] interpretation, the flysch can be regarded as „an orogenic facies on the frontal face of a dome which moved in one direction and accumulated detritus in its fore-deep", *the above structure developed continuously, beginning with the Late Cimmerian movements, in the period between the Austrian and Sava phases of the Alpine orogen.* (Should the detrital—pelitic sequence of Budafa—Inke be of a Lower Helvetian age, it might be concluded that these movements could have lasted in some places up to the Styrian phase). In the Carpathian Basin the main tectogenetic period was the Austrian phase: a fact evidenced by the hiatus and marked denudation phenomena generally observable between the Lower and Upper Cretaceous, in the East Alpine-Carpathian system (Bucegi conglomerates, Gosau series, etc.) and by the more complex structure of the Lower Cretaceous formations. which are thicker than the Upper Cretaceous. It was at this time that the Variscian masses, moving towards each other, and bounding the Tethys, brought about the present arrangement of the Alpine—Carpathian—Dinaric system. In the enviroment of the Carpathian Basin the ancient platforms hampered each-other's movement so that the territory of our country became an area of „relative pressure shadow" [F. HORUSITZKY, 1968] and was thus less affected by compression than the surrounding orogens were. The Cretaceous—Palaeogene tectogenesis, which took place in several phases — as proven by both the flyschoid sedimentation and the specific geological structure of the SW foreland of the Bakony Mts. explored by wildcatting [I. BODZAY, 1970] — was subordinate as compared to the manifestations of the Austrian folding.

In the Cretaceous—Paleogene „tectonic phases" our territory „was so greatly compressed" that „the compressed sequences, upon the subsequent geomechanical actions, already reacted as a uniform rigid consolidated mass... In this amalgamated mass mostly *fractures and fracture systems due to tensile stresses were later produced.* Young horizontal block dislocations, however,...provide evidence of *the fact that compression did not cease acting even later* [F. HORUSITZKY, 1968].

The most important event in the Neogene evolutional history of the Carpathian Basin has been the thinning and subsidence of the earth crust [L. STEGENA, 1967], supposedly due to subcrustal currents [E. SZÁDECZKY KARDOSS, 1968]. The resulting Pannonian Basin, formed in place of the earlier mountain system, has been filled up by the sediments of the Neogene archipelago.

Neogene tectonics consisted for the most part in a less intensive rejuvenation, with a lower intensity, of the Alpine fractures first of all the transversal ones. The faults and the less significant imbrications are due to „compression-bound stresses" while the graben-faults (Makó, Őrség, etc.) are connected with the subsidence of the basin. These are really beyond the scope of our study and thus have not been indicated on the maps. And the above hints at Neogene tectogenetical evolution have been given just to announce the subject to be dealt with in the next stage of this work.

CONCLUSIONS

According to the above, „the geological structure of Hungary does not represent an exotic case" strikingly differing from the Alpine-Carpathian background [F. PÁVAI VAJNA, 1930] and this „no man's land has much more Alpine and orogenetic characters than was believed before" [F. HORUSITZKY, 1961]. „The date and causes of origin of the Alps—Carpathians and the surrounded structures can be traced back to the same circumstances" [E. R. SCHMIDT, 1961].

In the pressure shadow formed between the Variscian masses the area of the Carpathian Basin has less been compressed than the surrounding orogens [F. HORUSITZKY, 1968], and because of that „it also possesses less self—dependent characteristics than the orogenes surrounding it" [E. SZÁDECZKY KARDOSS, 1970]. The lower degree of piling is therefore — also according to our opinion — not the consequence of a more rigid behaviour of the area, but is rather due to stresses of smaller amplitude gradually reducing inwards, which would essentially correspond to the notion of the median mass, in the sense redefined by ASHGIREJ, BRUNN, JANSHIN and BELOUSOV. In the Neogene, under the less subsided area the earth crust has become thinner, and the resulting basin was inundated by the Pannonian inland sea.

The work to be done in the future is to compile an exhaustive review of what has been outlined above, and to evaluate the potential resources of oil and natural gas in a similar monograph.

SUMMARY

The Upper-Palaeozoic—Mesozoic geosyncline of the Tethys, similarly to the World-Ocean of our days was a recipient of sediments, with real oceanic depths and clearly separable facies. On the area of the Eastern Alps and the Carpathians five structural units of the crust with different facies can be differentiated which may be characterized by various intensive subsidences of the basement. Going from the North to the South these are: the Outer-Carpathian, the Austro-Alpine, the Inner-Dinarian, the Bihorian and the Villányian units. The axis of the geosyncline could be supposed on the area of the Inner-Dinarian unit in the Carbon-Triassic, while in that of the Austrian Alpine in the Jurassic. The sediment sequences of these crustal structure units have taken up the form of a folded mountain-system during the Cretaceous-Paleogene are, and they have thrusted over one another.

The area of the Carpathian Basin has become compressed less than the surrounding mountain-systems. This is not the consequence of a more rigid behaviour of the area, but is rather a result of the relative pressure shadow developed between the Variscian masses moving toward each other. In the Neogene era, under the Carpathian Basin piled up and sunk in less extent, the earth crust has become thinner and the subsidence was flooded by the Pannonian inland sea.

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